Compensation of Space-Charge Effects by "*Electron Columns*"

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(thanks to A.Burov, G.W.Foster, V.Kamerdzhiev, G.Kuznetsov, Yu.Alexahin, V.Kapin, F.Zimmermann)

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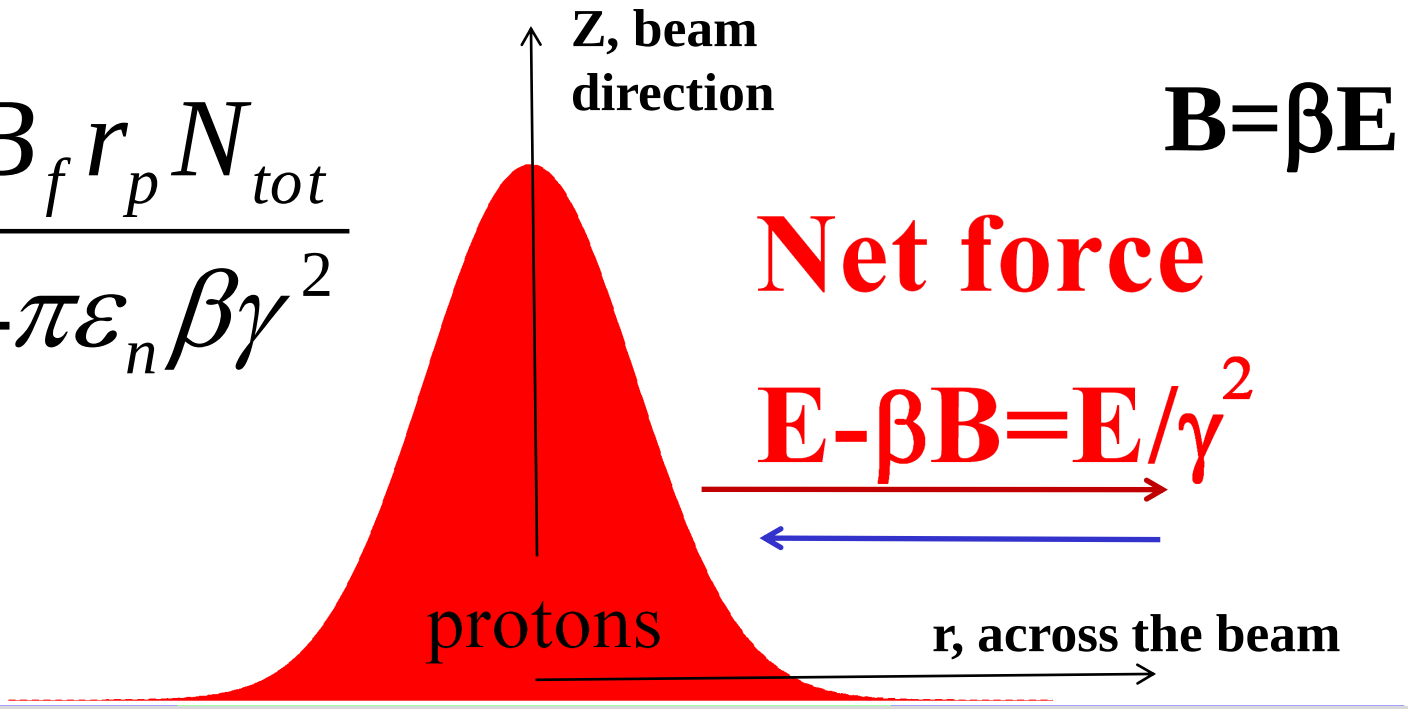
Space Charge Forces & Compensation

$$\xi_{SC} = \frac{B_f r_p N_{tot}}{4\pi\varepsilon_n \beta\gamma^2}$$

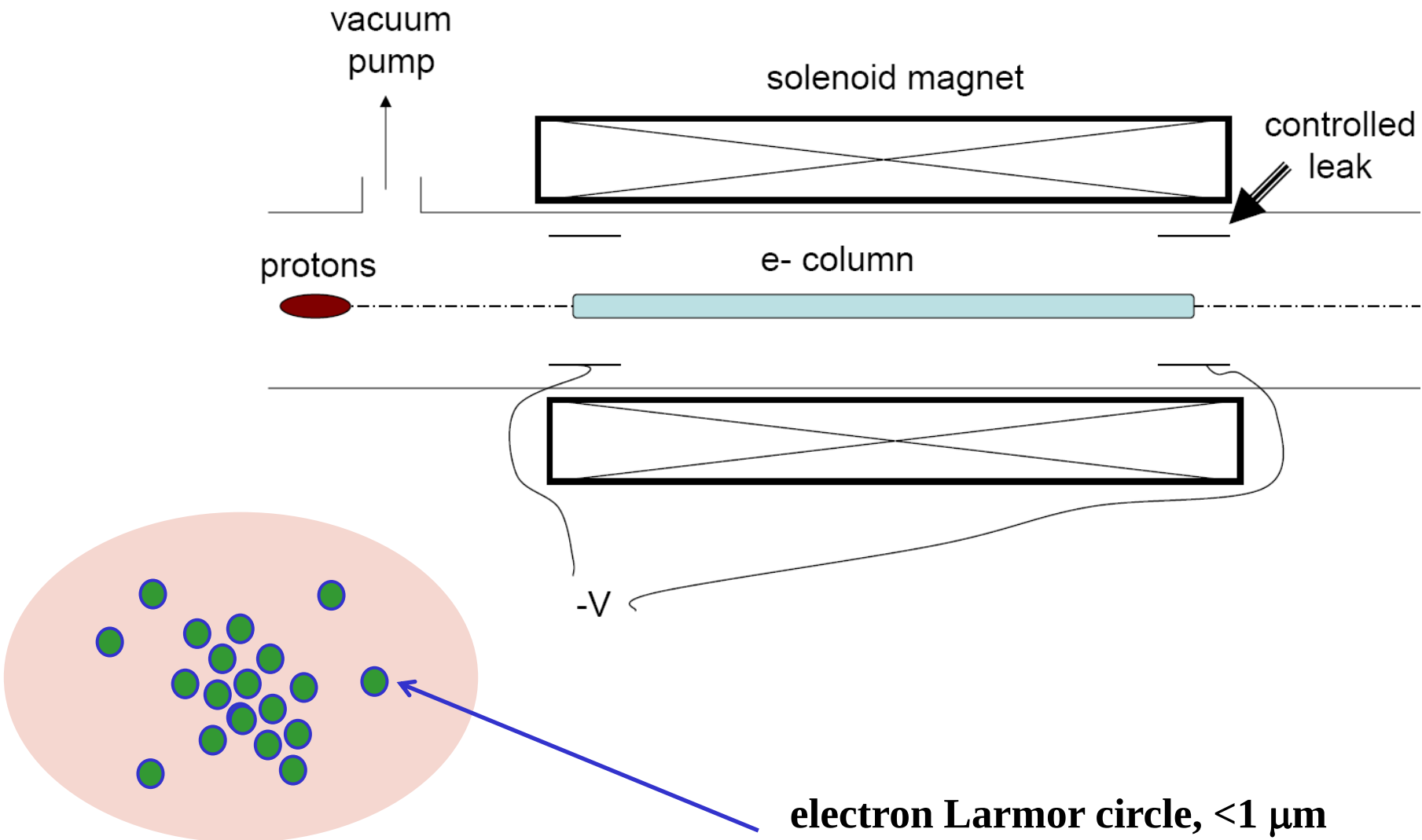


Difficulties, Facts

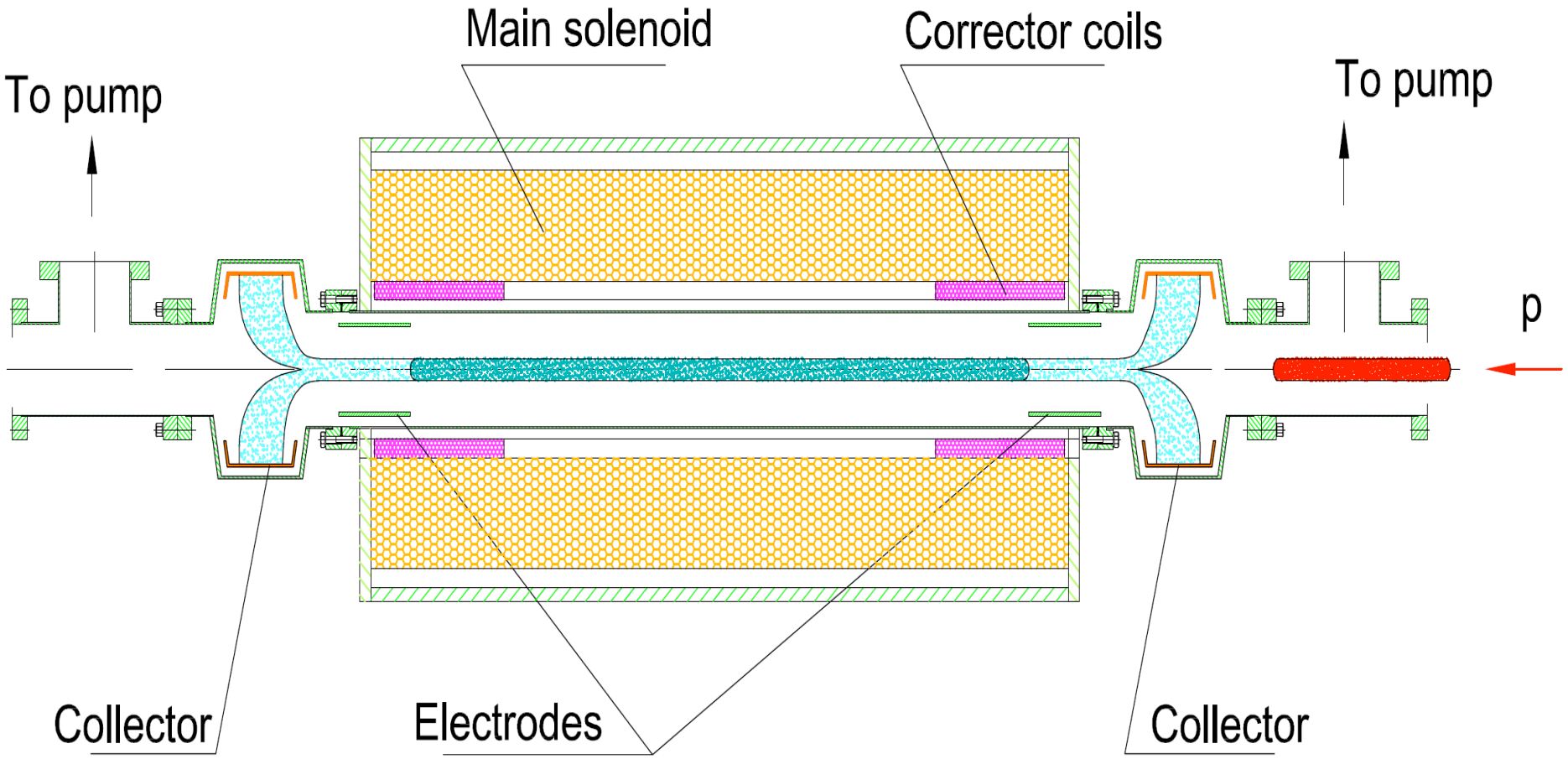
1. Stability of the system (transverse motion)
2. (Dynamic) matching of transverse p-charge distribution
3. Appropriate longitudinal compensation (for not-flat proton bunches)

- Some indications of success with few MeV protons and e- from injected gas (Novosibirsk, 1970's)
- The protons-electron system is VERY unstable
  - Now we now it as "electron cloud" effect
  - Vacuum worsening, beam instability, emittance growth
- E-lenses proposed in 2000 – difficulty with #2
- New idea which addresses #1, #2 and even #3 →

Electron Column



E-Column in reality



SCC with e-Columns

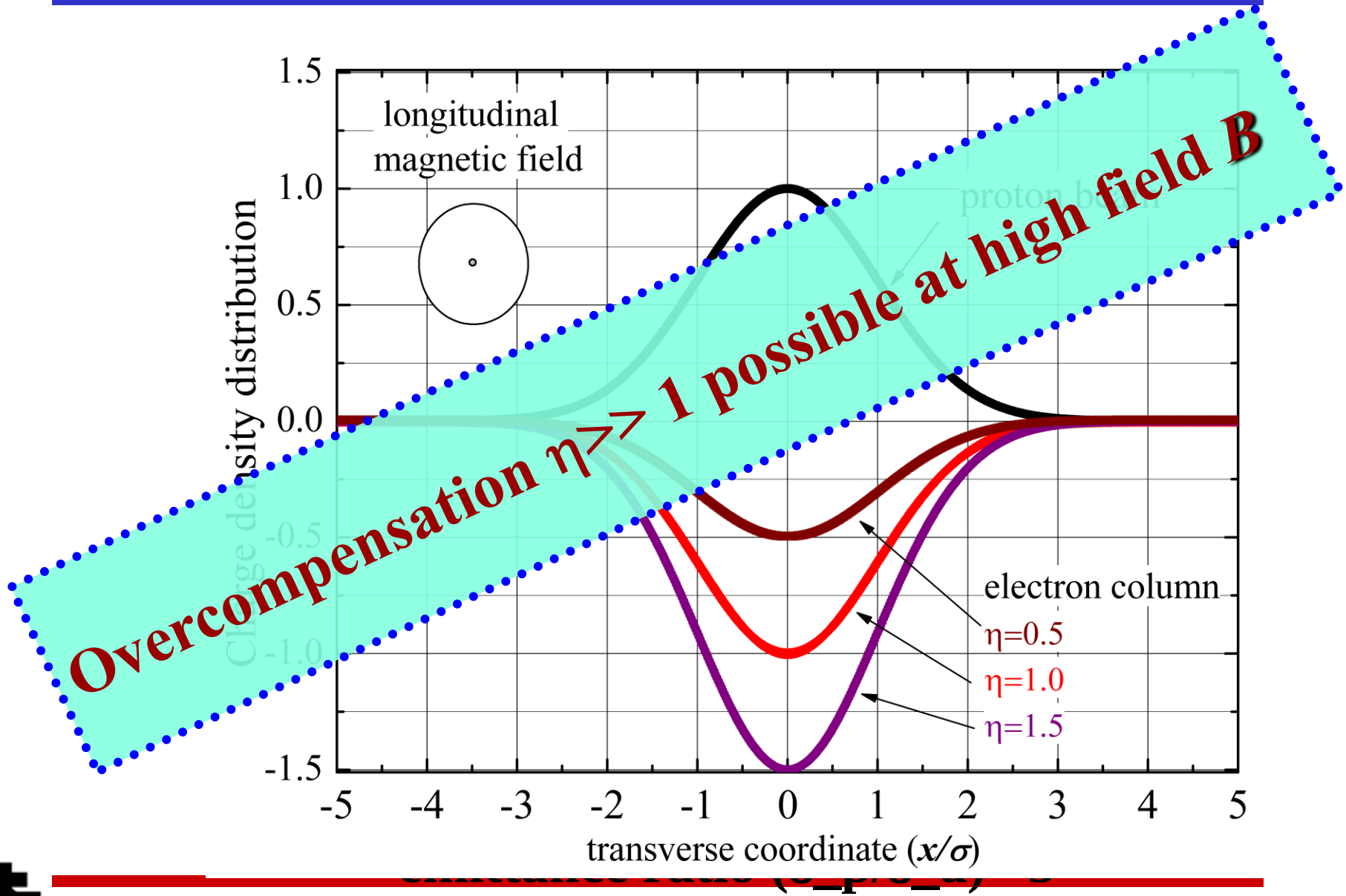
- Instead of uniformly distributing electrons around the ring with low concentration :

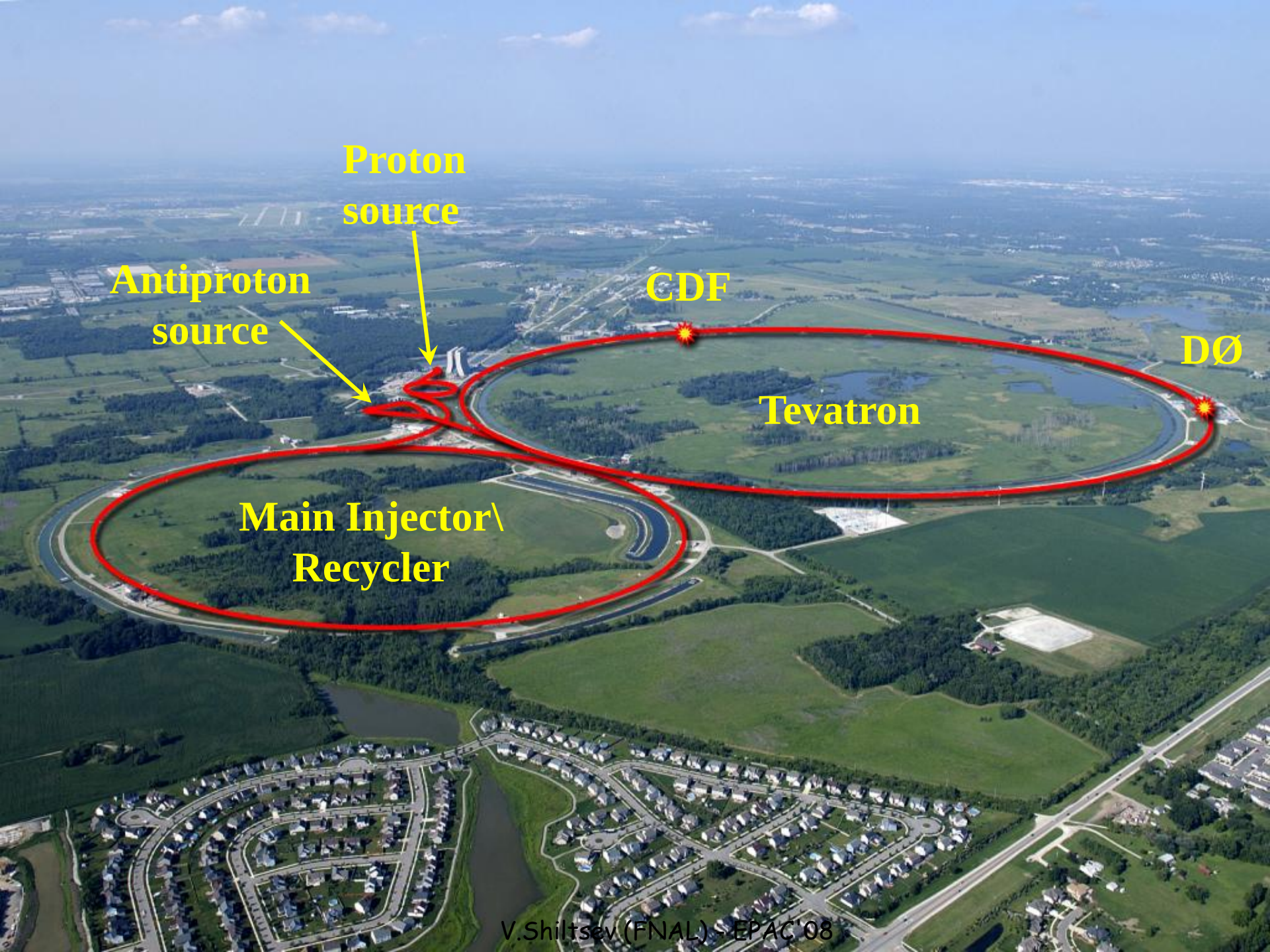
$$\eta = \frac{n_e}{n_p} = \frac{1}{\gamma^2}$$

- Electron columns will generate HIGH concentration of electrons but over a small fraction of ring circumference:

$$f = \frac{N_{EC} L_{EC}}{C} = \frac{\eta}{\gamma^2}$$

How high local η could be?




Proton source
Antiproton source
CDF
DØ
Tevatron
Main Injector\ Recycler

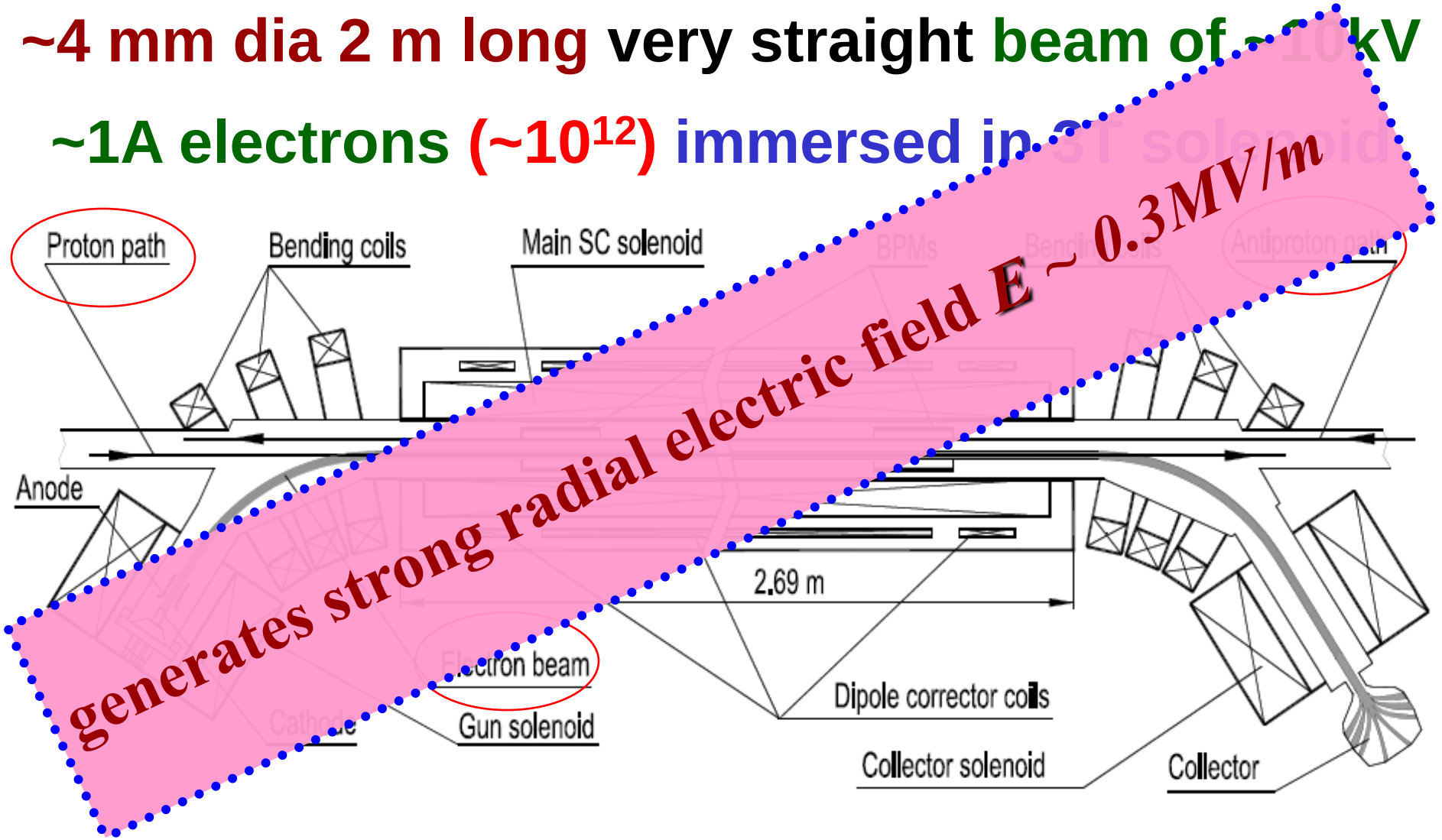
Some Examples

	C [km]	E[GeV]	ξ_{SC}	$N_{EC}L_{EC}$
Booster	0.48	0.4	~0.3	~120m
Main Injector	3.3	8.0	0.06+	~20m
Recycler	3.3	8.0	0.12+	~40m

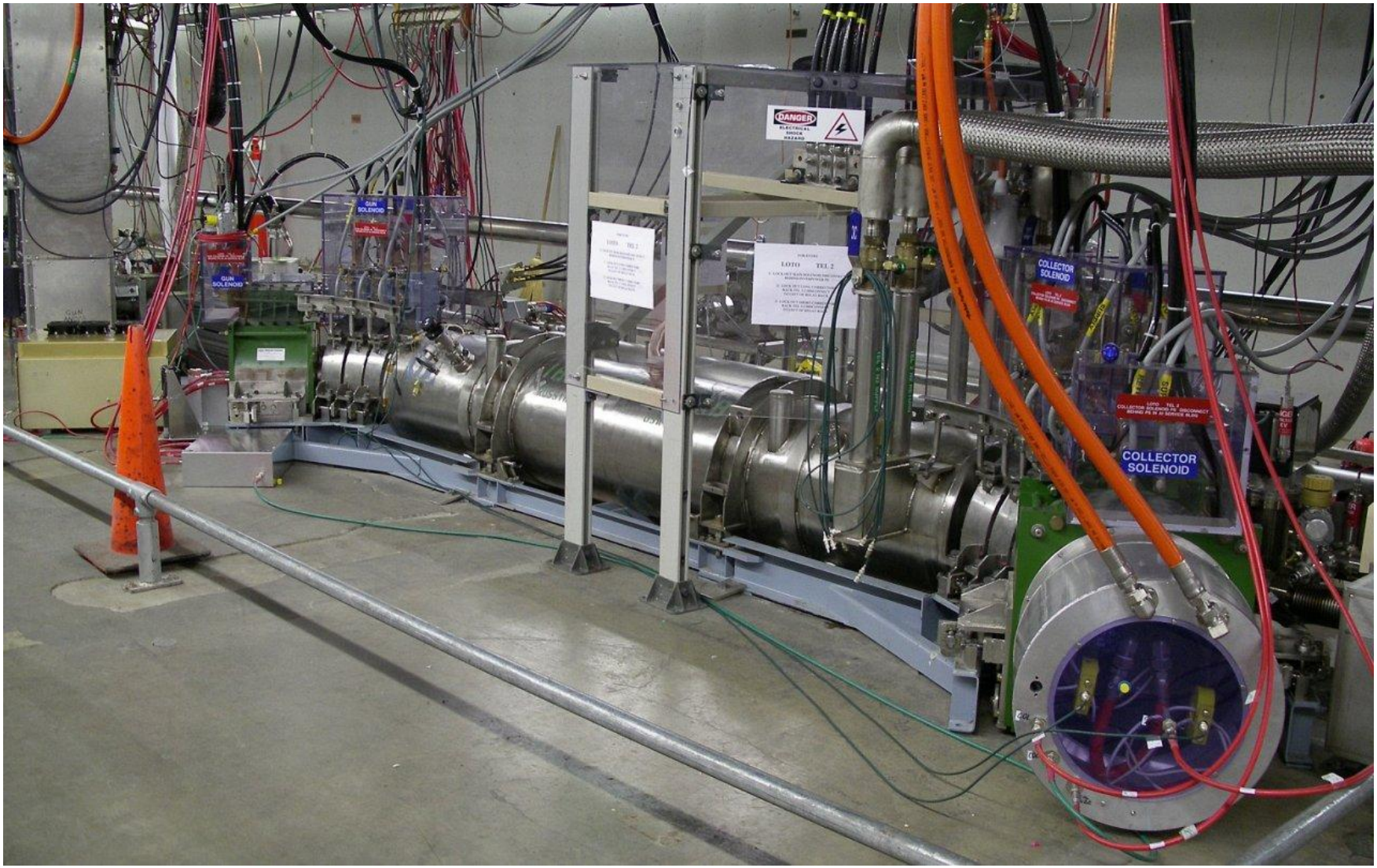
Compare with Electron Lens

~4 mm dia 2 m long very straight beam of ~10 kV

~1A electrons (~10^{12}) immersed in 3T solenoid



TEL2 In The Tunnel (A0)



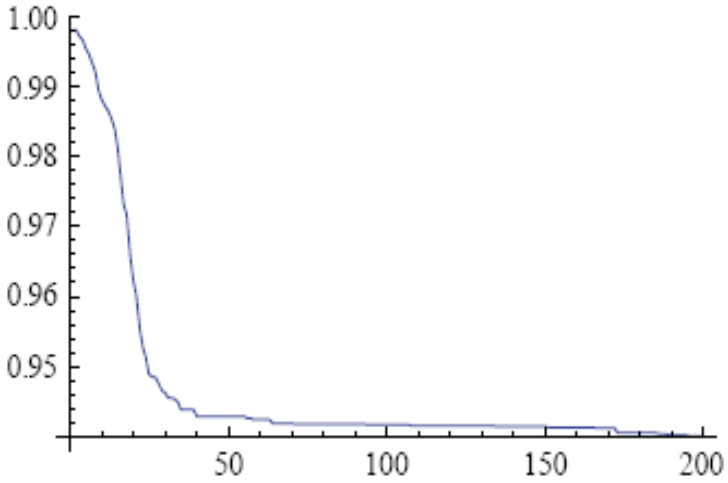
SCC Simulations with e-Columns

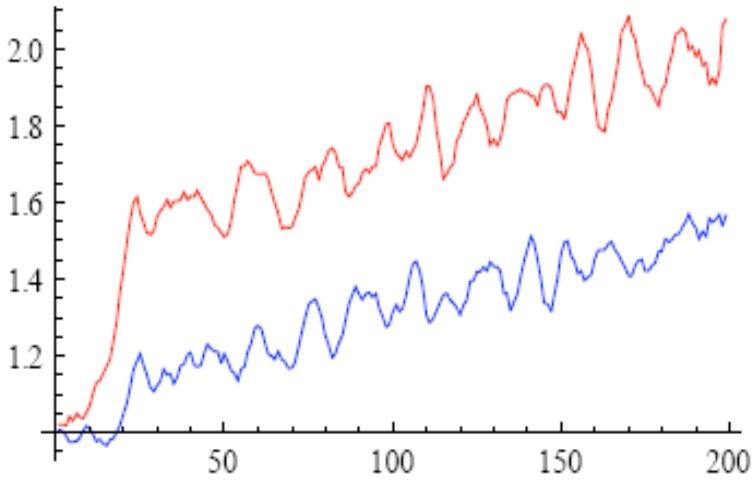
Yu.Alexahin
V.Kapin

N/N_0

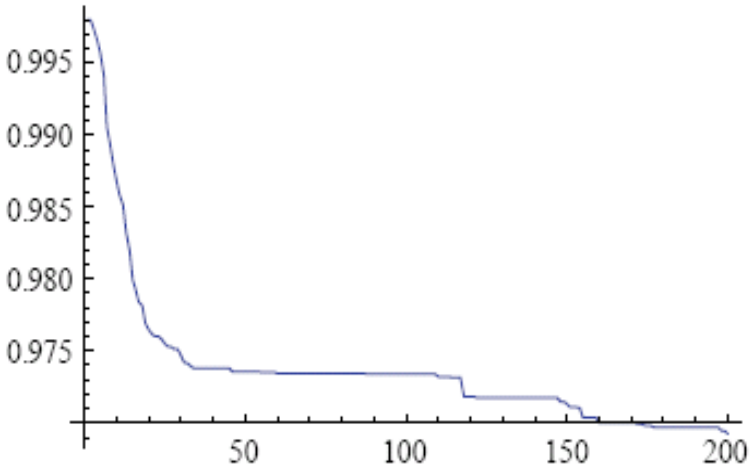
$\varepsilon_x/\varepsilon_0$, $\varepsilon_y/\varepsilon_0$

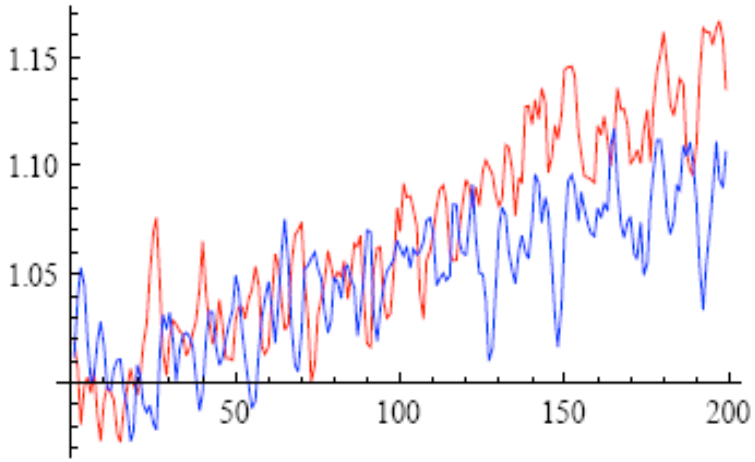
$f = 0$



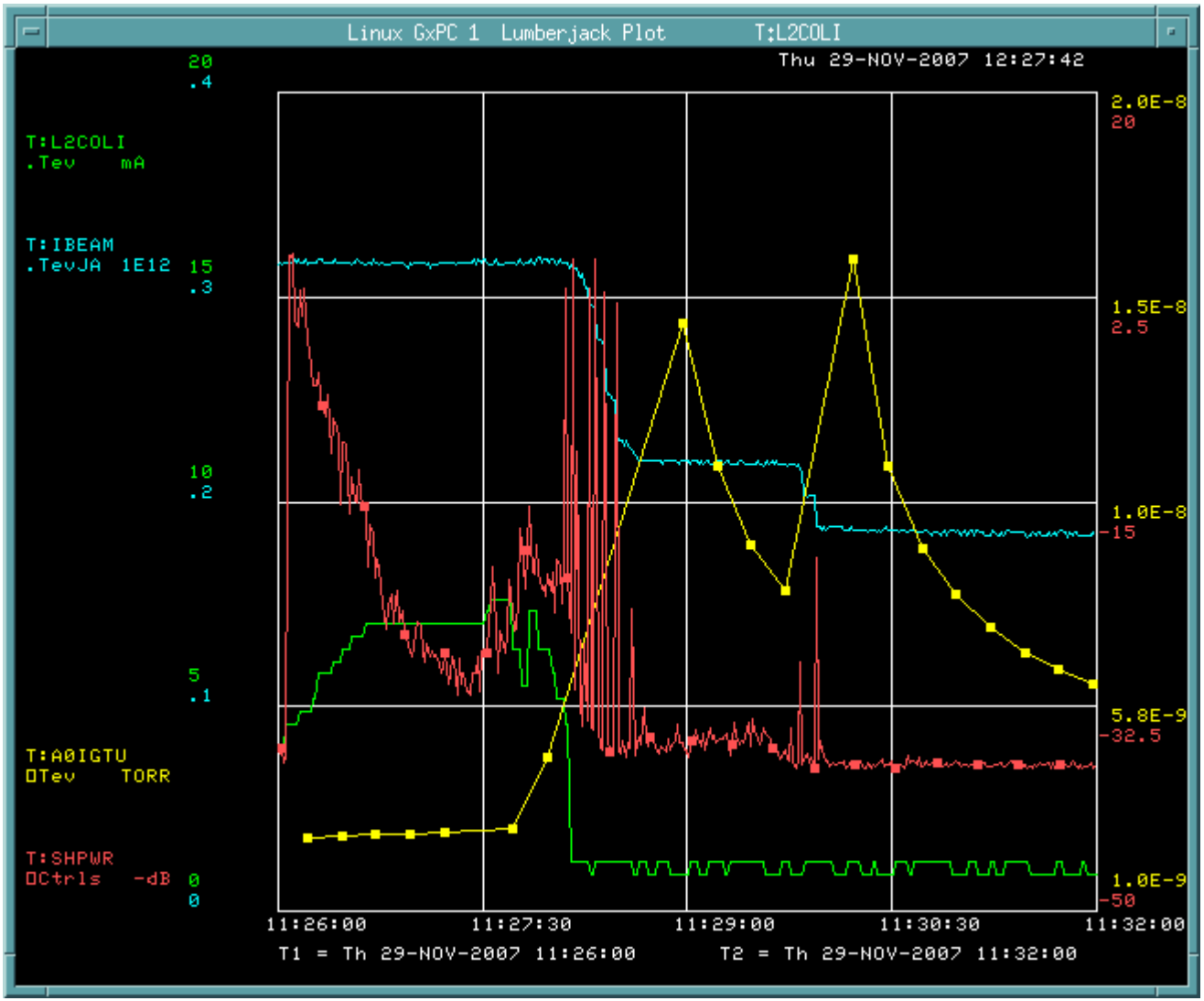


$f = 0.5$



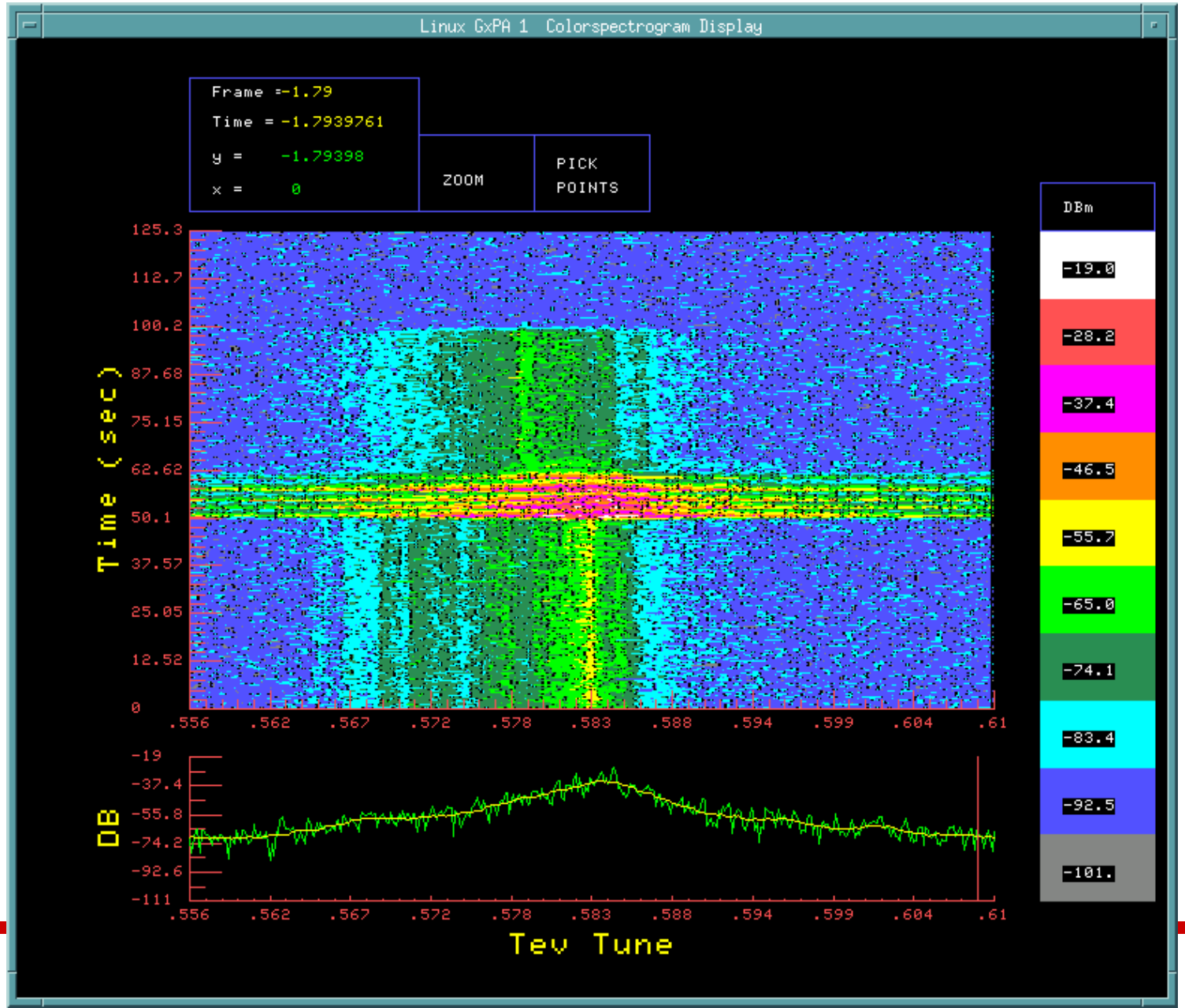


Spoiling Tevatron Vacuum by e-beam



emittance ratio (ε_p/ε_a) ~3

E-Column shifts tune by 0.004 at 150 GeV



Plans, Issues

- Further tests in the Tevatron to be performed with better vacuum control (1e-7, no e-beam help)
- Simulation and analysis to address:
  - Maximum B-field needed for high η
  - Tolerances on profile matching
  - How many (few) e-columns needed in SuperPeriod=1 machines like Main Injector and Recycler
  - ExB e-dynamics if proton beam x,y sizes are not equal
- …if successful- Build a (cheap) e-Column prototype for studies in MI
- … if successful - Build and install as many as needed for Space-Charge Compensation in MI and RR operation during *Project-X* era


That's All, Folks!

Back-up slides

FNAL Booster Bunching factor

$$\tau_n = \frac{1}{\sigma_{ioniz} \cdot \beta_p \cdot n_0}$$

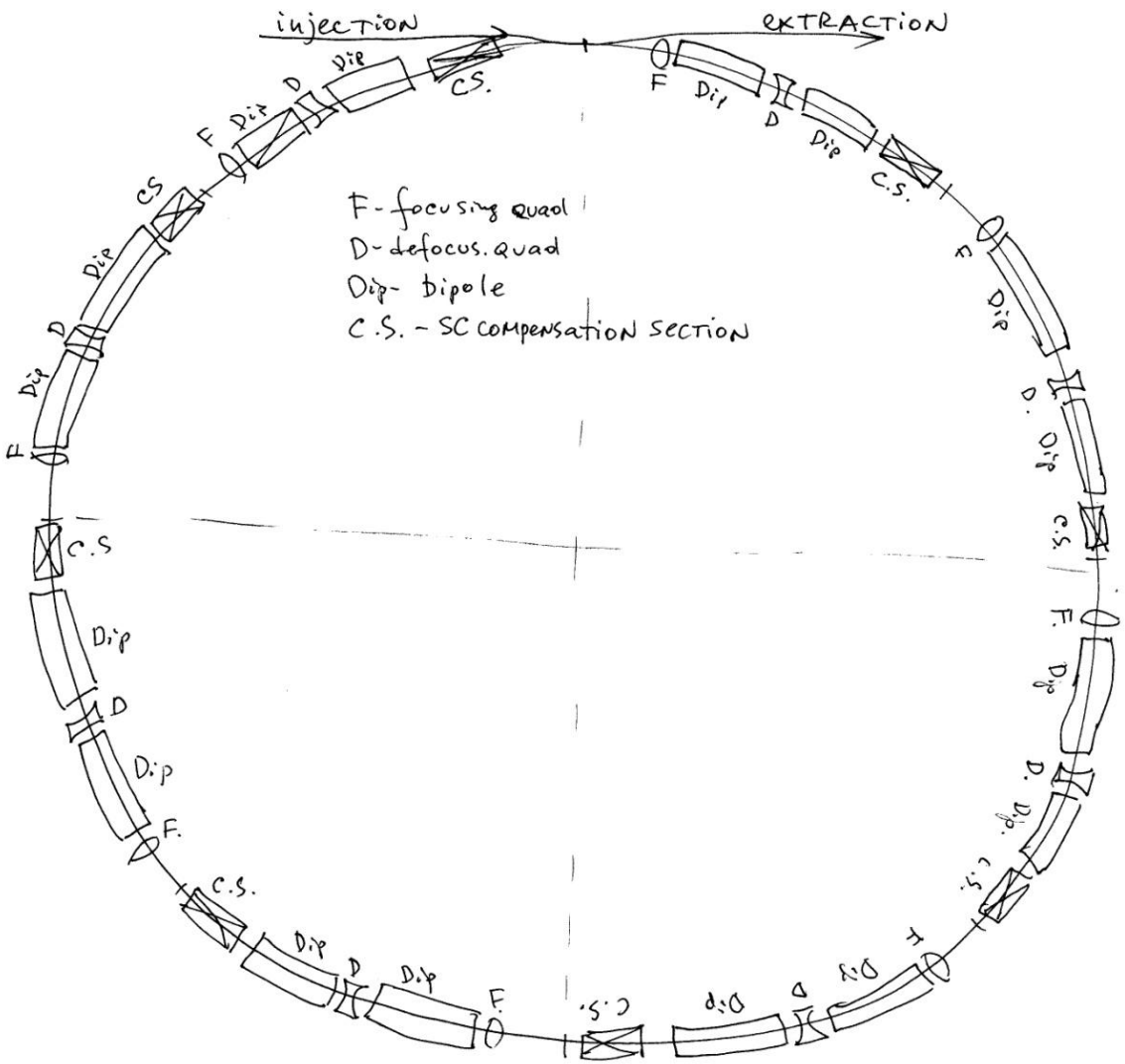
$$\sigma_{ioniz} \approx 2 \cdot 10^{-17}\ cm^2$$

$$n_0 = \frac{2.5 \cdot 10^{-10}}{P\ [Torr]}\ cm^{-3}$$

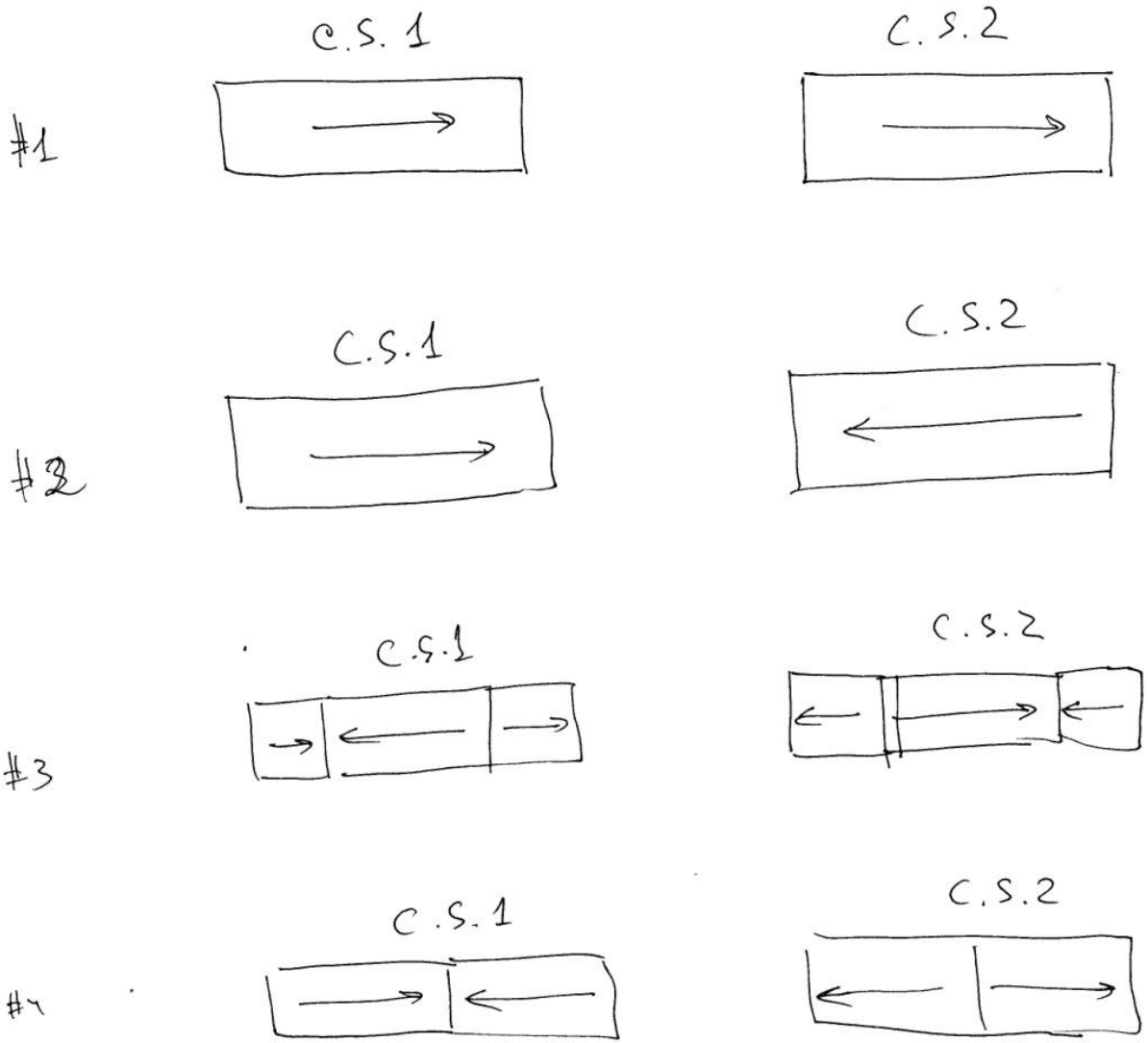
$$\tau_n \approx \frac{0.05\ nS}{P\ [Torr]}$$

$$\beta_p \approx c$$

Ideal ring with e-columns



Possible Solenoid Configurations



FNAL Booster Bunching factor